U.S. Army Coastal Engineering Research Center

A FEASIBILITY STUDY OF A WAVE-POWERED DEVICE FOR MOVING SAND

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by
Frederick F. Monroe

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ABSTRACT

A model of a wave-powered, sand-moving device, suggested by the staff of the U. S. Rubber Company Research Center, was tested for its feasibility as a dredging device early in 1965 at the U. S. Army Coastal Engineering Research Center. Sixteen tests were made under various wave conditions at a 1:15 scale reduction. Waves with prototype periods of 5, 7, 9, and 15 seconds were tested. Wave heights varied from 1.1 to 4.4 prototype feet in prototype offshore depths of 38.7, 34.5, and 30 feet. In half of the 16 runs, more sediment was accreted landward of the dredge than was eroded and deposited seaward of it, yet, in only two of these tests was the shoreward accretion significant. On the other hand, of the eight tests that resulted in erosion on the shoreward side of the device, five showed significant amounts. Accretion landward occurred when the dredge was operated in shallow water over a nearly horizontal bottom. Over a sloping bottom, the dredge served generally to erode material and deposit it downslope. These results indicate that the device, at least in its present form, is unsuitable for use in moving sand shoreward from offshore sources, and that further testing in the prototype is not justified. Despite the disappointing results, the operation of the device illustrates the possibility of a great potential for the utilization of wave power.

FOREWORD

Artificial beaches have proven to be so successful and economical as a means of shore protection that in some localities there is now a scarcity of onshore sources of hydraulic fill. Presently seismic explorations are seeking offshore sources of sand that could be recovered by ocean-going hopper dredges. A device, such as the one tested here, could prove invaluable in moving sand to the turbulent zone from the limit of deep-draft dredge operation.

Frederick F. Monroe, an Oceanographer in the Research Division, conducted the tests and prepared the report under the general supervision of Thorndike Saville, Jr., Chief of the Research Division. During the time of the tests, Colonel F. O. Diercks was Director of the Center, and at the present time, J. M. Caldwell is both Acting Director and Technical Director.

NOTE: Comments on this publication are invited. Discussion will be published in the next issue of the CERC Bulletin.

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A FEASIBILITY STUDY OF A WAVE-POWERED DEVICE FOR MOVING SAND

by

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I GENERAL

1. Introduction

A model of a wave-powered sand-moving device, suggested by the staff of the U. S. Rubber Company Research Center, was tested for its feasibility as a device for moving sand toward shore, at the U. S. Army Coastal Engineering Research Center, Washington, D. C. from 1 Jaunary 1964 to 15 March 1965. The purpose of the series of tests was to determine whether the model operated sufficiently well to justify further testing in the prototype or at very large scale. It had been suggested that a successful prototype would provide an economical means of moving sand from offshore through water too shallow for standard floating dredge operation to the beach area itself, or to within reach of a beach-based, permanently placed suction line, or dragline.

The possibility existed that such a device could be useful in the general program of proposed beach improvement around the shores of the United States and other areas, particularly if offshore sand deposits, presently being sought, proved to be of sufficient size and quality to warrant their being used as borrow areas for beach replenishment. If practicable, nearshore sources could provide sand for beach nourishment or possibilities might exist that an ocean-going dredge could unload within the reach of the wave-powered sand-moving device which would then transfer the sand to the surf zone. Although the use of devices such as modified amphibious military craft have been proposed for this purpose, the development of an economically operated and soundly engineered machine has remained elusively beyond the reach of existing technology. An additional benefit to be derived from the use of a wave-powered sand-moving device is that it would use naturally available energy to move considerable sand quantities to shore, except for the winching and emplacement phases of operation.

2. Description of Device

The model wave-powered sand-moving device used in this study was shipped to the Coastal Engineering Research Center on 28 October 1964 by the U. S. Rubber Company, which had done considerable preliminary development and testing. The initial development of the device is covered in a report by Rhodes.* This model, as received, consisted of two flotation pads composed of synthetic closed-cell rubberoid foam, located fore and aft, and attached

*Rhodes, T. J., Memorandum on Wave-Dredging Systems, United States Rubber Company Research Center, Wayne, New Jersey, March 4, 1963.

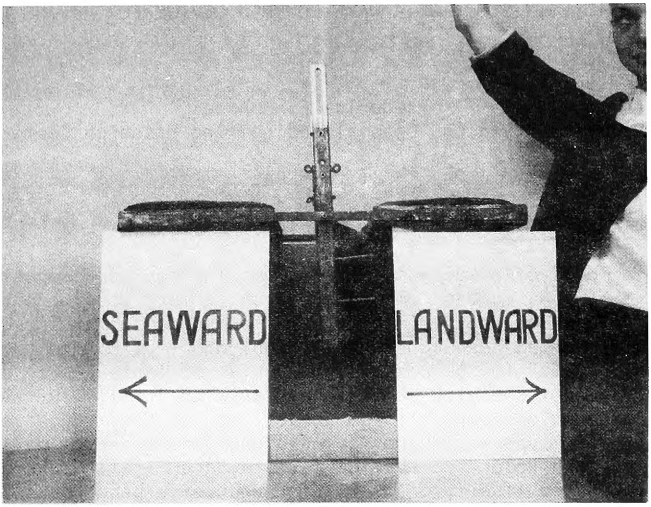

Figure I-a   View of Device Showing Check Valves in Open Position

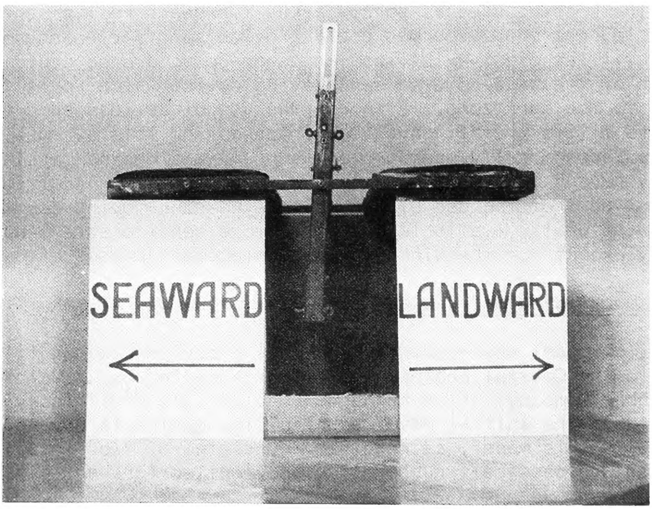

Figure I-b View of Divice Showing Check Valves in Closed Position

by two laterally located horizontal beams. The waterline of the device, in fresh water, lay along the center of these rigid beams. Suspended outside these beams and pivoting on the connecting rod to them, was a pair of rigid vertical members, between which were held four fiberglass flaps acting as check valves, with lead sheathing on their lower edges to speed their closing (see Figure I-a). With this configuration, the device could be operated only in a constant water depth sufficient to utilize all 4 flaps. The configuration was modified by narrowing the flap valves and placing their supporting vertical beams inside the horizontal beams that connected the flotation pads. In this way, the apparatus could be either raised or lowered by moving the rod from a particular flap valve and replacing it through a lower, or higher, valve as desired. Hence the dredge could be operative and in various water depths (in shallower water than before its modification).

3. Operation of Sand-Moving Device

Theoretically, the sequence of operation of the sand-moving device is as follows. The device was initially floated over the shoreface seaward of the breakers. Then a wave crest passed, causing the submerged valves to open landward (Figure I-a), allowing the orbital current to pass through them unobstructed, except for the energy required to open the valves. With the passage of the subsequent trough, a seaward directed current is generated. This current closes the valves and creates a very powerful current downward and seaward, under the device (see Figure I-b). This current causes considerable scour beneath the device if it is located a relatively short distance above the surface of the bottom. This scouring action places large amounts of sediment in suspension on the seaward side of the device. The presumption then was that with the passage of the next wave crest, the suspended sediment would be flushed through the opened valves and deposited on the landward side. Thus material is removed from under the dredge, placed in suspension to seaward, and carried shoreward and deposited by the shoreward component of the orbital current. By moving the device slowly shoreward, the mound of deposited material ahead of it would be progressively transported inshore.

II TEST SETUP

1. The Wave Tank

The test series took place in a wave tank which measures 85 feet in length, 14 feet in width, and 4 feet in depth, and has a series of transparent glass panels, spaced about 10 feet apart along one side, and an eccentrically driven pusher-blade type of wave generator at one end. This tank was modified somewhat for the testing of the wave-powered sand-moving device. The modification consisted of the construction of a narrow flume along a portion of the windowed tank wall. The narrow flume was necessary to fit the size of the model device so that the waves would not act around it, and to minimize the needed amount of the sand simulant which was fine coal. In addition, the narrowness of the flume allowed the remainder of the shoreward end of the tank to be used as an absorber beach to eliminate

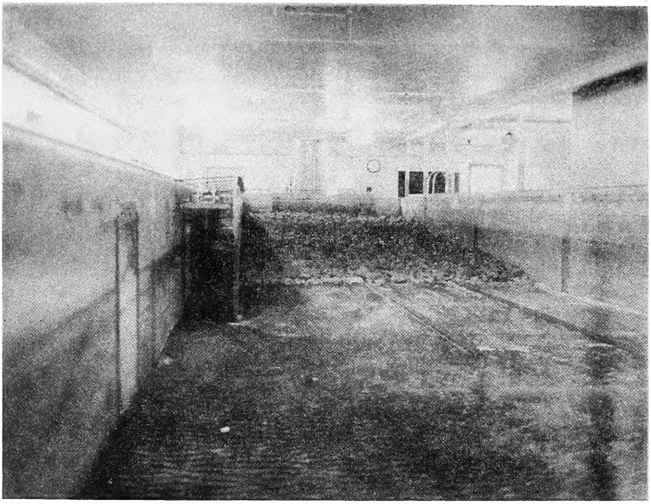

Figure 2 View of Flume and Absorber Beach Setup (taken after testing)

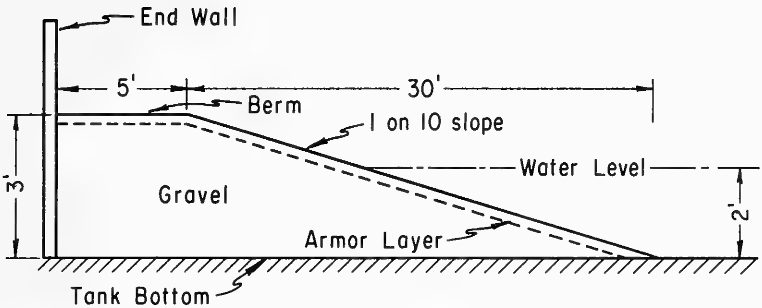

Figure 3-a Cross Section of Absorber Beach Profile

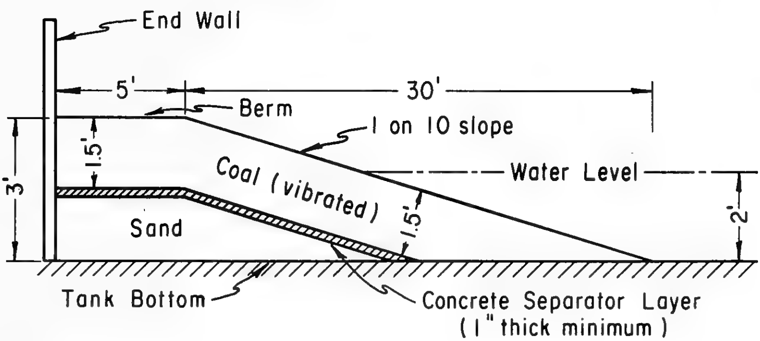

Figure 3-b Cross Section of Test Flume Profile

reflected waves (see Figure 2). To create the flume, a splitter wall, 40 feet long and 4 feet high, was constructed of 3/4-inch plywood, and rigidly fastened in the tank, extending from the shoreward wall toward the wave generator, parallel to, and 1.5 feet from the windowed wall of the tank. To prevent seepage of either sediment or water from the flume, a bead of caulking was placed between the base of the splitter wall and the tank floor.

2. Absorber Beach

After construction of the wall, an absorber beach, composed of gravel overlain by angular rock about 4 inches in diameter was placed on a 1:10 slope in front of a 5-foot level berm between the splitter wall and the tank side opposite the flume. The height of the absorber against the shoreward wall was 3 feet. The absorber beach extended 35 feet toward the wave generator (see Figure 3-a), and 12.5 feet horizontally along the tank width, creating an extensive absorber area.

3. Sand Simulant Profile

The sediment profile over which the wave-powered sand-moving device was to be tested was molded in the flume, or obtained as a result of wave action on a previously molded beach. Initially, a lath shim was fastened to the splitter wall delineating the initial profile to be molded. In order to further minimize the amount of crushed coal needed to simulate to reasonable scale a beach sand which might be encountered in the prototype, a supporting underlayer of sand was first placed in the tank and capped with a 1-inch layer of concrete. A 1.5-foot layer of crushed anthracite coal (the sediment simulant) was then placed atop the supporting underlayer. The coal was shoveled into the flume, vibrated underwater, and molded into a 5-foot level berm, extending toward the generator from the shoreward wall, then sloping with a 1:10 slope to the tank bottom 35 feet from the shoreward wall (see Figure 3-b).

4. Sand Simulant Characteristics

The anthracite coal used in the study has been compared with quartz sand in previous beach deformation studies at the Coastal Engineering Research Center. It had been found that the coal behaved in the model in much the same way as the quartz sand did in the prototype at a scale reduction roughly similar to that used in this study. For that reason it was selected as the bottom sediment material for the wave-powered sand-moving device study. The median diameter of the coal grain was 0.2 millimeters; the average specific gravity was about 1.52 versus 2.65 for quartz sand. The coal grains had been found to have a settling velocity in fresh water of about 4 centimeters per second.

5. System for Moving Device

After placement of the coal slope, the system for moving the device was installed in the flume. A hand-operated winch was fastened to a rectangle of angle irons that had been attached to the plywood splitter wall

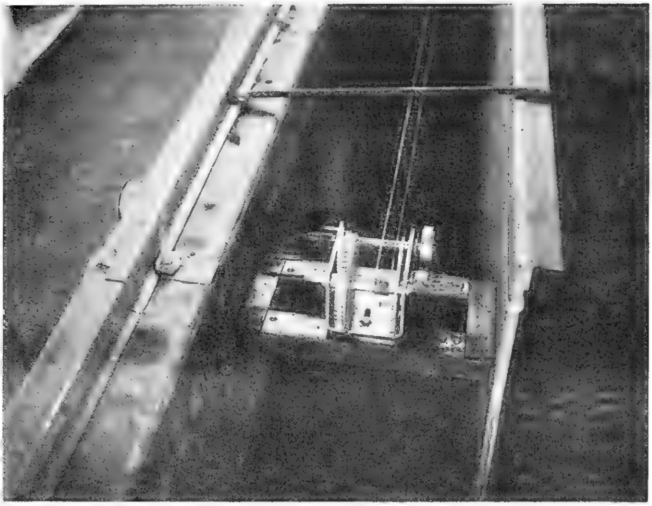

Figure 4-a   Winch for Moving Device

Figure 4-b   Shoreward Section of Cable System

and the tank side wall at the generator end of the flume. A 3/8-inch diameter cable was wound several times around the winch and passed through a sheave that was connected to a turnbuckle which was, in turn, attached to the shoreward wall, and made continuous by fastening the ends together with U-clamps (see Figures 4-a and 4-b). This system allowed the device to be moved back and forth about half the length of the flume, limited only by the inability of the U-clamps to pass either through the sheave or around the winch. The device was then connected to the overhead winching cables by smaller cables attached to the vertical flap valve supporting members on each side of the device above and below the flotation pads. This configuration allowed the device to be moved by the wave action in a dominantly vertical direction unhindered, but restricted to a very small amount of its horizontal motion, back and forth in the flume in the direction of wave motion; the flume walls, of course, eliminated any lateral motion.

6. Establishment of Equilibrium Profile

Before testing for each wave condition, the slope was brought to an equilibrium profile using the waves to be tested. First, the water level, measured near the generator blade over the concrete tank bottom well away from the flume, was set at 2.0 feet using a stationary point gage. The model period for the waves to be generated was established using the vari-drive of the eccentrically driven pusher-blade type wave generator. The desired wave height was then established by trial and error by setting the eccentric arms that controlled the amount of horizontal movement of the generator blade. The generator was then started, and the resultant wave heights were measured with a two-wire resistance type wave gage located in 2.0 feet of water just outside the mouth of the flume. By this process, the desired wave height was obtained and waves were allowed to impinge on the coal slope until it was estimated the near-equilibrium had been established over that section of the profile on which the device was to operate. The equilibrium profile for the initial wave condition tested was always established by about 40 hours (about 155 prototype hours) of wave action. Whether or not a profile had reached equilibrium was determined by periodic soundings every 0.5 feet along the flume. The soundings were then reduced to a datum and plotted graphically against the profile from the preceding survey. Figure 5 on page 34 shows the equilibrium profile for the initial wave condition for Run 1 compared with the molded slope before any wave action.

III TEST PROCEDURE

1. Test Types

The actual testing procedure began after the equilibrium profile was established. Two basic types of tests were conducted. In the first type, a static test, the device remained at a single location in the flume for the duration of the test. In the second type, a mobile test, the device was moved a prescribed distance by a winch and cable after a certain amount of wave action, usually more than one hour in the prototype (about 20 minutes in the model).

2. Water Level

Throughout the test program, the water level gage remained at the same location, and prior to each run, the water in the tank was measured and established at the desired level.

3. Wave Height Measurement

A resistance type stainless steel dual-wire probe was suspended in the water in the estimated center of the flume at approximately the location proposed for the device for the ensuing test run. This probe was fastened to a flat carriage that spanned the width of the tank, and could roll from one end of the tank to the other over level rails on top of the concrete sidewalls. The wave-height sensing probe, once in position, was linked to a 2-channel pen-motor recorder. The wave gage recorder system was balanced and calibrated before and after each run of short or moderate duration, and periodically during long runs. Also, the sensing probe was adjusted to record linearly.

4. Wave Height and Wave Period Calibration

The eccentric arms of the wave generator control the length of the blade movement which determines the height of the wave. The period of the generator is, of course, the period of the wave and can be checked by stop-watch. Approximately 3 minutes of wave action were allowed prior to recording the waves for height analysis to allow tank effects to reach an equilibrium state with respect to the waves being generated at that time. After the 3 minutes, wave heights were analyzed immediately, and the eccentric setting of the generator arms was altered until the desired wave height was obtained. Then all wave action was stopped and the surface of the coal in the flume was surveyed and its profile drawn.

5. Profile Surveying Technique

Two technicians surveyed the flume bottom profile. A technician on the carriage sounded the depth of the coal surface with a modified Philadelphia rod attached to the carriage and fitted with a foot to prevent its penetration into the coal. A measuring tape, 40 feet long, was attached to the inside wall of the flume where it could be easily read by another technician who also pushed the carriage to the desired location and noted the depth reading and its location on a data sheet.

6. Slope Remolding

After a series of runs involving the use of the device, the bottom was sometimes deeply entrenched and uneven. If this was the case, it was felt that variable shoaling and reflection effects might well cause erroneous results, and the coal bed was remolded. The wave conditions for the run subsequent to remolding were set on the generator and the water was drained below the level of that segment of the bed to be remolded. Crushed coal was added

and moved by hand, and the surface smoothed to conform to the desired 1:10 slope. The water level was then raised above the disturbed portion of the coal surface. The bottom was then vibrated throughout the disturbed portion by means of a heavy submersible penetrating mechanical vibrator. The water level was then lowered, the volume of material needed to offset compaction was added, and the surface resmoothed. Usually, only about a 1-inch layer of coal was lost to compaction, so that the vibration was done only once. Once the slope was remolded, the water level was set at the desired depth, and the adjusted wave generator was started. The system was then allowed to run to approximate equilibrium as defined by a lack of change on the survey profiles to a point approximately 10 feet seaward of the proposed starting location of the device. A suitable equilibrium state was normally attained after about 40 hours of wave action. The flume was then judged to be ready to receive the device again.

7. Device Placement

The device was then placed in the flume with its flaps opening in a landward direction. Four cables, bifurcated and attached to the top and bottom of the vertical flap valve supports, were fastened to the overhead cable by turnbuckles and U-clamps. The fastening cable was sufficiently loose to allow the device to float at its normal level, yet sufficiently tight to keep the device from moving either landward or seaward. The flume walls restrained lateral movement of the device without interfering with its vertical oscillations.

8. Device Operation

With the device in place, the generator and height-recording apparatus were started. Wave action was allowed to continue for about 20 minutes (one hour and 17 minutes in the prototype) for static and mobile tests. At the end of the selected time, for a static test, wave action was stopped. For a mobile test, at the end of the initial period of wave action, the device would be rapidly winched landward, usually about 0.2 feet (equivalent to about 3.0 feet in the prototype). After the same length of time, the landward winching process would be repeated. Wave action would not be stopped during the entire mobile test.

9. Run Termination and Analysis

At the end of a run, wave action would be stopped, the device removed from the flume, and the coal surface in the flume surveyed. The results of this survey would be graphed as an overlay and compared with the pre-run survey. This comparison clearly illustrated the areas of accretion and erosion in the vicinity of the device. A quantitative analysis of accretion and erosion, on both sides of the device, was made by planimetering the graphed areas of concern. The results of these analyses from the basis of the conclusions on the feasibility of the device for moving sand.

10. Scale Relationships

The test series was conducted on a reduced scale of roughly 1:15. Representative profiles obtained during the study are shown in Figures 5 through 21; all dimensions are in actual model terms unless otherwise specified. In Tables 1 through 8, both model and prototype terms are listed where applicable. Prototype terms are computed according to Froude relationships as follows: linear dimensions, such as length, height, width, and depth are obtained by multiplying the actual model dimension by a factor of 15: that is, 1 foot in the model is equivalent to 15 feet in the prototype. Volume dimensions, such as the amount of sediment moved by the device, are computed by multiplying the actual model volume by a factor of 15^3, or 3375; for example, 0.2 cubic feet in the model is equivalent to 675 cubic feet in the prototype. Time dimensions are computed by multiplying the actual time in the model by a factor of the square root of 15, 3.873, so 1 hour of actual running time in the model is equivalent to 3.873 hours, or 3 hours, 52 minutes in the prototype. In the discussion of the individual test runs, *prototype terms will be used throughout unless otherwise specified.*

IV RESULTS

1. General Description of Figures 6 through 21

Figures 6 through 21 show the profiles that existed prior to and after each run, and thus show the effect of the device operation for each run. For contrast, a 4X vertical exaggeration was employed. The tank wall at the end of the tank opposite the generator is represented by the left side of the graph. The solid line represents the profile that existed prior to each run, and is so labeled; the dotted line shows the profile as it existed after each run. The numbers along both the ordinate and abscissa of each graph represent actual (not prototype) distances in the model in feet. The stillwater line is shown for each run and is so labeled. The water depth, measured outside the flume near the wave generator, labeled "offshore water depth", the wave period, and the wave height are listed for each run in both model and prototype terms. The wave height listed is the average of the wave heights recorded during each run as measured by a dual-wire resistance probe located outside the mouth of the flume in roughly the same depth as the offshore water depth.

In each of the first seven runs (Figures 6 through 12) the location of the wave gage between the device and the shore is marked and labeled. Each position occupied by the device for any period of time is also marked on each of the graphs showing the effects of device operation. It should be noted that the dotted line (post-run) profiles do not always extend the entire length of the solid line (pre-run) profile. By observing the device in operation for short periods of time, it seemed that the area directly affected extended only about 3 model feet on either side of the device. This observation was severely limited by the shortage of window area in

the tank wall. Some profiles were thus taken only to show these direct local effects, and so extended only a portion of the length of other profiles.

2. General Description of Tables 1 through 8

Tables 1 through 8 list variously the basic conditions that existed for each run, and some of the changes caused by the presence and operation of the device.

Table 1 lists the test type of each run; that is, whether the device remained at a single location throughout a run, a static test; or whether it was moved periodically during the run, a mobile test. The condition of the slope prior to each run is also listed, that is, whether the slope was in approximate equilibrium with the wave condition to be tested, or whether the slope was the result of the preceding run. This listing defines the solid line profile on Figures 6 through 21. The length of time each run lasted is also noted in Table 1, in model terms, in minutes and in equivalent hours and minutes for prototype derived by reducing the model times to hours and multiplying them by the square root of the scale factor, 3.873, according to Froude relationships.

Table 2 lists the offshore water depth, wave periods, and average offshore wave height that prevailed for each run, in both model and prototype terms.

Table 3 lists the changes in the average wave height caused by the presence and operation of the device for Runs 1 through 7. The offshore wave gage, as noted in Figures 5 through 21, was placed outside the mouth of the flume in 2 feet of water in the model, the equivalent of 30 feet in the prototype (except as specified in Table 2). This measurement was made a distance offshore from the end wall of the wave tank of 43 feet in the model, 645 feet in the prototype. The inshore wave gage was located at various places between the device and the intersection of the bottom profile with the stillwater line. Due to the changing profiles, this gage was operated in various water depths and located as shown on the comparative profiles for the first seven individual runs (Figures 6 through 12). The use of this gage was terminated after Run 7 due to calibration problems. The inshore gage was located an average distance of 10.4 feet in the model, or 156 feet in the prototype, from the end wall of the tank. Another column in Table 3 lists, for the applicable runs, the percentage of average wave height reduction inshore of the device caused by its presence and operation.

Table 4 lists the location of the device at the beginning and end of each run relative to the end wall of the wave tank in both model and prototype terms. An additional column lists the distance the device was moved in mobile tests, again in both model and prototype terms.

Table 5 defines the device setting for each run, that is, the depth (in feet) of the deepest part of the device below the stillwater surface

in both model and prototype terms, and the number of flap valves operating. The depth of the deepest part of the device is the distance from the waterline on the device, down to the lower edge of the lowest flap valve. The number of flap valves operating during a run was equal to the number of valves extending below the axial supporting rod through the uppermost acting valve, the vertical valve supports, and the horizontal flotation pad support beams. The inactive valves were attached to the vertical valve supports as were the active valves, but were suspended above the flotation pads and thus out of reach of impinging waves.

Table 6 lists the effect of the presence and operation of the device on its landward side. Table 7 lists, similarly, the effect on its seaward side. In the case of a static run, the landward side of the device was defined as that portion of the pre- and post-run profiles extending from the station over which the device was located, proceeding toward the intersection of the bottom profiles with the stillwater line as far as the device was believed to have caused changes. The seaward side, also in the case of a static run, was similarly defined, but in the opposite direction. In the case of a mobile run, both the seaward and landward effects were defined beginning immediately under the *final* rather than the initial position of the device. These tables list the computed volume of sediment in both model and prototype terms, either accreted, that is, where the post-run profile had a higher elevation above the bottom than the pre-run profile, or eroded, where the post-run profile had a lower elevation that the pre-run profile. These volumes were derived, in model terms, by planimetering the two-dimensional area of the comparable profiles, and multiplying this value by the width of the flume. The prototype volume was then obtained by multiplying the model volume by the cube of the scale factor, 15^3, or 3375, with both model and prototype values given in cubic feet.

Table 8 lists the net effect of the presence and operation of the device in two columns headed "Landward" and "Seaward", in both model and prototype terms. These two columns show results of the summation of Tables 6 and 7, respectively. For example, Table 6 lists the amount of accretion of sediment on the landward side of the device after Run 1 as 0.007 cubic feet in model terms. Also, the amount of eroded sediment on the landward side is listed as 0.003 cubic feet. Therefore, by subtraction, the net resultant is accretion of 0.004 cubic feet on the landward side. Like procedures were followed to obtain the remainder of Table 8. The real significance of this table is, however, somewhat uncertain. As has already been stated, the profile surveys made after each run covered only that portion of the bottom that was suspected of having been affected by the presence and operation of the device. The distance covered, therefore, was extremely variable; for example, after Run 1, a distance of 2 (model) feet was covered on the landward side, with 3 feet being included in the post-run profile on the seaward side. In contrast, however, a very noticeable bar was formed inshore of the device during Run 7, so the surveyed profile was expanded to cover 2.6 model feet landward and 5.5 feet seaward of its final position.

The uncertain significance of Table 8 lies in the origin of the resultant accreted sediment, and in the deposition of the eroded sediment. In addition to the variable survey coverage, other possible sources of the discrepancies between the net landward and net seaward quantities of accreted and eroded sediment, which should theoretically balance, can only be qualitatively explained. One explanation is the loss of suspended sediment, seaward of the device, out into the main part of the wave tank. This loss most certainly occurred to some extent as coal was noted in the form of small ripples over the entire tank bottom after the tank had been drained. Some of the sediment in several runs was contributed by the shoreward erosion of the bottom profile. Some sediment was probably moved to the measured bottom profile by the migration of the ripples into the flume from the main wave tank. In addition, some sediment may have been moved by the device from the seaward to the landward side and vice versa.

Other possible contributing causes for the existing net discrepancies may be error in measuring, plotting and in planimetering the comparative profiles. It is likely that some combination of each of these various possibilities did occur. Nevertheless, a run resulting in a net accretion on the landward side of the device should be viewed as successful, although, with waves of extremely long period, such as in Runs 14 through 16, the natural tendency is to build the beach. The contribution of sediment movement by the device therefore remains somewhat indefinite, even though compared to generally near-equilibrium conditions. Experience indicates that for the waves of low steepness, more sediment would have accreted landward of the position of the device had the device not been present. However, in the case of impinging, shorter period (high steepness) waves, accretion landward should be viewed as significant.

3. Discussion and Results of Runs 1 through 16

a. Run 1. Figure 5 on page 34 illustrates the differences between the molded slope and the profile as it had evolved in approximate equilibrium with the prescribed wave conditions at least sufficiently far seaward to cover the location at which the device was to be placed. The nearshore concavity and offshore convexity of the equilibrium profile are normal for waves of such a short period as 5 (prototype) seconds. The equilibrium profile thus established, the device was placed about 237 feet offshore from the intersection of the stillwater line with the equilibrium profile, in water having a depth of about 18.75 feet (see Figure 6).

The device was set at its deepest setting so that its lowest flap valve was touching the bottom. At this setting 4 flap valves were operating and the topmost rod was connected to the vertical valve supports through the top hole set, one hole above the uppermost valve. On the landward side of the device most of the 10 cubic feet of sediment that was eroded was derived from the immediate vicinity of the device, while the accretion on the landward side was composed of a rather thin, uneven layer of sediment, having a volume of about 24 cubic feet, covering an area landward of the device location for a distance of about 40 feet. The trough dug by the device, which accounted for most of the erosion landward of the location of the

device, continued even more deeply to seaward and accounted for the erosion of 35 cubic feet that took place on that side of the device. Seaward and downslope from the trough, 49 cubic feet of sediment accreted in a rather thick layer extending about 36 feet seaward of the downslope trough limit, about 48 feet from the device. Run I lasted about 50 minutes so the sediment movement took place at a rather rapid rate. Waves having an average height of 1.8 feet in 30 feet of water impinged on the device and were reduced in height 22 percent to 1.4 feet by its presence and operation. The resultant energy released was used primarily to operate the device and to move sediment.

The device, located in front of a window in the sidewall of the tank, could be observed in operation. However, after the first few waves, the water was filled with suspended sediment which severely limited visibility and photography. The activity that took place very close to the window could be seen and gave the impression that the sediment in suspension was primarily present in two vortexes, one on either side of the device, with the seaward one being considerably larger in extent.

These vortexes rotated rapidly, but at different rates, directions, and at different times, the main impetus being provided by the trough-generated current that flowed in a seaward direction beneath the device. This current caused the larger, seaward vortex to spin in a counterclockwise vertical direction at a rapid rate when the trough was passing. This spin direction seemed to continue at a decelerating rate for some time after the trough had passed and the passage of the subsequent crest had begun, then accelerated again with the oncoming trough. Most of the seaward deposition seemed to take place as the vortex was slowing down, beginning farther seaward and progressing toward the device. As the crest passed, some sediment was seen to flow through the opened flap valves but, relative to the whole seaward vortex, the amount seemed to be quite small.

Similarly, a smaller vortex was observed on the landward side of the device. This vortex seemed to spin rapidly in a clockwise direction when the trough was passing, but reversed direction with the passage of the wave crest and spun counterclockwise quite slowly until the subsequent trough arrived. The sediment on the landward side of the device was deposited during the short periods of time when the spin reversal was taking place, which may account for the thinness and unevenness of the accreted layer. The narrowness of the window in the tank wall prevented observation of the full scope of the activity within the flume, and observation from above was prohibited by the density of the black suspended material. The net effect of the presence and operation of the device was to produce an equal net accretion of 14 cubic feet over the surveyed areas of both sides of the device. Due to the limitations of the post-run survey, it is not known where the accreted material came from, but a net accretion on the landward side of the device was at least initially promising though of such small amount as to possibly be within the error of measurement.

b. Run 2. For Run 2, the device was moved landward some 4.0 feet from its location during Run 1 (see Figure 7). The profile over which the device was to operate was the same as existed at the end of Run 1. For this run, the wave period was the same as for the preceding run, 5 seconds, but the average wave height in 30 feet of water was lowered to 1.5 feet. The average wave height was decreased by the device only 7 percent, to 1.4 feet, during this run. Run 2, like Run 1, was a static test and lasted 50 minutes. The setting, too, was the same, with 4 flap valves operating; the edge of the deepest was about 20 feet below the stillwater surface and in contact with the bottom at the start of the run. On the landward side of the device, thin layers of sediment, totaling 22 cubic feet and 21 cubic feet accreted and eroded, respectively. In Run 2, most of the erosion that took place in the trench dug by the device, both seaward and landward of its location. The heaviest deposition took place on both sides just beyond the periphery of the trench, with the main portion of landward deposition occurring within about 32 feet of the trough rim. Most of the seaward deposition was occupied with filling the trench dug during Run 1, while some erosion took place seaward of the trench in some of the accreted material that had been deposited during Run 1. On the seaward side, 19 cubic feet of sediment eroded and 25 cubic feet accreted, hence the device produced a net accretion of 6 cubic feet on that side. This result is indicative of the increased hydraulic activity that took place on the seaward side of the device although still within the limits of measurement accuracy.

c. Run 3. The device was located about 32 feet farther landward for Run 3 than for Run 2, and quite close to the base of a rather steep offshore slope in the bottom profile (see Figure 8). As the device was to be operated in shallower water than the preceding two runs, its flap valves were raised one setting so that the rod connecting the flap valve rack to the vertical supports was passed through the uppermost flap valve, causing the lower edge of the deepest valve to extend about 15 feet below the stillwater line, just in contact with the coal bed that existed after the completion of Run 2. Four flap valves operated during the run, however. Run 3, like the two preceding runs, was static, with the device staying in the same location for the 50-minute duration of the run. The wave conditions were the same as during Run 2, with a period of 5 seconds, and an average offshore wave height of 1.5 feet in 30 feet of water. The device reduced the wave height quite significantly by 47 percent during the run, cutting the average height from 1.5 to 0.8 feet. This was perhaps a consequence of proximity of the device to the steep offshore slope. The effect of the slope was very noticeable with regard to the volume and location of the sediment transplanted by the device. On the landward side of the device, no accretion occurred, but 4 cubic feet eroded. Again the erosion took place primarily in the trench dug by the device on both the landward and seaward sides. A very slight amount of erosion occurred for a short distance immediately landward of the trough. On the seaward side of the device, 27 cubic feet of material eroded, and 48 cubic feet accreted.

As before, most of the erosion took place in the trench, the accretion occurring as a sizable mound decreasing in thickness seaward, beginning at the seaward rim of the trench and tapering in thickness downslope after continuing to fill the trenches made during Runs 1 and 2. The net effect

of the presence and operation of the device was net erosion of 4 cubic feet from the landward side of the device, and a net accretion of 22 cubic feet on the seaward side. This net transfer of sediment seaward is probably an indication of the effect of the steeper slope a short distance landward of where the device was operating. That sediment which was flushed landward probably slid down the slope into the trench and thence was transported to the seaward side.

d. Run 4. For this run, the device was moved about 17 feet farther inshore than it had been for Run 3 (see Figure 9). The wave period remained at 5 seconds, and the offshore water depth at 30 feet, but the offshore average wave height was increased slightly to 1.6 feet. In order to accommodate the lesser water depth, the rod connecting the flap valve rack to the vertical supports was passed through the second flap valve from the top, thus placing the uppermost flap valve almost totally above the waterline of the device, and completely removing it from effective dredging operation. With this configuration of three operative valves, the lower edge of the bottom flap valve extended to a depth of about 14 feet beneath the stillwater surface.

Like the preceding three runs, Run 4 was a static test, and of the same 50-minute duration. The dredge setting and/or location had a profound effect on the wave height as the average offshore impinging wave height was 1.6 feet, while the average wave height measured at a gage inshore from the device was only 0.7 feet, a reduction of 56 percent. After Run 4, the entire profile was surveyed to see what changes had occurred over its length during the preceding portion of the test series. This survey showed that a rather small amount of headward erosion of the shore had occurred above the stillwater line, in addition to the movement and slight enlargement of some of the small nearshore bars (see Figure 9). In the vicinity of the device, Run 4 produced the usual trench and increased the steepness of the slope immediately landward of the device. The depth of the trench was less than in previous runs; the width was about the same. Some accretion also took place on the rim of the steep slope landward of the device. Offshore, there was a small amount of filling in the trench left by Run 3, but some erosion of the seaward rim. Still farther seaward, a small amount of accretion took place. In that portion of the profile landward of the device, about 123 cubic feet of material accreted, while some 189 cubic feet eroded. Seaward of the device, the profile was surveyed some 83 feet. Downslope from the trench, 62 cubic feet had eroded, while 27 cubic feet had accreted. The presence and operation of the device during this run produced a net erosion of 66 cubic feet on its landward side and a net erosion of 35 cubic feet on its seaward side. Presumably, accretion occurred seaward, outside the surveyed area.

e. Run 5. Run 5 comprised the first mobile run of the test series, that is, the device was moved a specified distance landward periodically without any cessation of wave action (see Figure 10). The pre-run profile was that which existed at the end of Run 4. The initial location of the device was inshore of that of the preceding run by only about 4 feet, so that it remained at the same setting with three valves operating.

Run 5 was of 7 hours and 43 minutes duration in all and the device was moved 3 feet landward about every hour and 10 minutes, for a total landward movement of 15 feet. The wave period was 5 seconds and the average wave height offshore in 30 feet of water was 1.5 feet. The device, over the entire run, reduced this wave height only 27 percent to 1.1 feet. As this run was the first of its type in the series, a survey of the whole bottom profile was made after the run. Only a small amount of headward erosion of the shoreline occurred, with, as in Run 4, some movement and enlargement of the nearshore bars. In the vicinity of the device, however, some rather spectacular changes occurred. Evidently, the usual trench was dug beneath the device, but only that segment of the trench which was dug in the final position is shown in Figure 10, with the rest having been backfilled. The landward progression of the device eroded the steep slope, noted in the discussions of the two preceding runs, and placed only a small mound of accreted material on its landward side. This landward erosion amounted to 218 cubic feet, while the amount accreted was only 134 cubic feet, a net loss of some 84 cubic feet of sediment. Seaward of the device, however, only 89 cubic feet of material eroded, all from the steep slope, i.e., that portion of it that became the trench as the device was moved. Seaward of the rim of the final position trench, all of the material, about 248 cubic feet, accreted. This material took the form of a long, deep, flattopped mound, extending from the final position trench of Run 5 to over the landward rim of the trench created during Run 3. Offshore of this mound was a dip reflecting the filling of the Run 3 trench, and a subsequent mound reflecting the seaward rim of this now-buried trench. Beyond this point, the mound of accreted material tapered down rather sharply to the pre-run profile. In all, only 89 cubic feet of sediment eroded, while some 248 cubic feet accreted on the seaward side of the device, a net gain seaward of 159 cubic feet.

From the results of Runs 4 and 5, it was concluded that the device, when backed by a rather steep slope, contributed sediment some distance offshore; much of it to points seaward of the device. It is likely that the steepness of the slope landward of the device was too great for any accretion to take place on it.

f. Run 6. For Run 6, the device was located about 18 feet landward from the apex of the mound accreted at the inshore rim of the steep slope during Run 5 (see Figure 11). Due to the shallow depth of the water at this location, the device was set at its highest setting, that is, the rod connecting the flap valve rack to the vertical supports was passed through the lowermost flap valve, making only one valve operable, the remaining three being suspended above the waterline. At this setting, the lowest edge of the flap extended about 5 feet beneath the stillwater surface. This run was static, the device remaining at the same location for the hour and 17-minute duration of the run. The waves had a period of 5 seconds and an average height of 1.4 feet in 30 feet of water. The presence of the device again served to reduce the average wave height inshore of the device, but produced only a 14 percent lower wave, with an average height of 1.2 feet. The device dug the usual trench but during this run, probably due to both the shallow water depth and the length of time the device was operated at one location, the trench was wider and deeper than those noted

during preceding runs. The mound which accreted during Run 5 on the landward rim of the steep slope and some of the upper portion of that slope eroded away. Most of the sediment derived from this erosion filled the trench dug at the base of the slope at the final device position of Run 5. During Run 6, the profile inshore of the device had a gentle slope and subsequently was more receptive and retentive of the sediment placed in suspension and deposited by the device. The largest mound of accreted material was deposited just landward of the inshore rim of the device-dug trench, with smaller assemblies of accreted sediment farther landward. In all, on the landward side of the device within the distance covered by the survey, 62 cubic feet of material accreted and 46 cubic feet eroded, resulting in a net inshore gain of 16 cubic feet. Seaward of the device location, however, 58 cubic feet of sediment eroded, while 25 cubic feet accreted in the distance surveyed, giving a net loss of 33 cubic feet.

The accretion of such a volume of material on the landward side of the device tends to support the hypothesis that the device operates more effectively on a gentle slope than on a steep slope.

g. Run 7. Run 7 served as a mobile test of the device in shallow water, over a more moderate slope. As in Run 6, only one flap valve was operable. The initial location was 9 feet inshore of the position during Run 6, and it was operated in waves having a 5-second period, but only a 1.1-foot average height in 30 feet of water. Due to the mound of accretion that developed during the run, the inshore wave gage had to be moved to various locations as noted on Figure 12. The average inshore wave height, computed from the various gage measurements, was reduced by the presence and operation of the device, about 46 percent to 0.6 feet. As a small amount of sediment had been accreted on the landward side of the device during Run 6, one of the main purposes of Run 7 was to attempt to move the mound farther inshore, and, if possible, enlarge it in the process. For the duration of this run, the device was moved shoreward 3 feet approximately every hour and 56 minutes, for a total running time of 25 hours and 10 minutes, and a total distance of 36 feet.

The results of this run were most interesting. About 14 feet landward of the final device location, beginning at the inshore rim of the device-dug trench, was a large mound of accreted sediment which attained a maximum elevation of 0.75 feet above the stillwater line. This mound of accreted material terminated about 40 feet inshore from its point of origin. This occurrence resulted in the creation of an offshore bar with a back bay inshore of it. The beach area profile, however, changed almost negligibly. The trench beneath the device was deeper and wider than any previously noted. The trench created during Run 6 was filled for the most part by the accretion of material placed during Run 7, but no other accretion occurred within the surveyed area seaward of any of the device locations. Landward of the final location, 218 cubic feet of material accreted and only 35 cubic feet eroded; the net accretion of 183 cubic feet was in the form of the inshore bar. Seaward of the final location, 38 cubic feet of sediment had accreted and 319 cubic feet had eroded, a net erosion of 281 cubic feet.

One noticeable difference in the behavior of the device during this run versus its previous behavior was that the flotation pads rose and fell vertically with considerable force. This flapping created what appeared to be a possible pumping effect caused by the rapid passage of wave crests. This phenomenon may or may not have had an effect on the creation of the large mound of accreted material inshore from the device.

h. Run 8. The main purpose of Run 8 was to attempt to move the large mound that accreted inshore of the device during Run 7, still farther inshore, and up on the beach. As many be seen in Figure 13, this did not happen. For Run 8, the wave period remained at 5 seconds, but the average offshore wave height in 30 feet of water was increased from 1.1 feet to 1.5 feet. The device remained at its same setting, with one flap operating, for the entire run. The run was of the mobile type, and the device was placed 3 feet seaward of its final position at the end of Run 7. The device was moved 3 feet every hour and 56 minutes, without stopping wave action, for a total running time of 38 hours and 44 minutes, covering a total distance of about 57 feet. The most noticeable effect of this run was the total erosion of the large mound accreted in the previous run. This material not only filled the trench made during Run 7, but caused a considerable amount of sediment to be accreted on the surface of the shelf near the seaward edge of the device, but also down the steep offshore slope and beyond. A small trench was dug during Run 8 at the location beneath the final device position, and a small amount of accretion was noted adjacent to the device on its landward side. Due to the proximity of the device to the shoreline, as well as calibration difficulties, the inshore wave gage was not used during this run, nor for the remainder of the test series. No measure of wave height reduction by the device was thus obtained.

Figure 10 shows the amount of accretion landward of the final position of the device to be small; planimetric analysis showing that 30 cubic feet of material were accreted, and 25 cubic feet were eroded, a net accretion of 5 cubic feet. Seaward of the final location, however, some 483 cubic feet accreted within the limits of the survey, while 472 cubic feet eroded, a net gain of 11 cubic feet (the net value being within the errors of measurement).

The pumping effect of the flotation pads of the device, as noted in the discussion of Run 7, was not observed during Run 8, which may account for the very limited amount of accretion that took place landward of the device. This run destroyed all the good effects observed in the previous run and showed essentially that a mound of material, accreted in shallow water, landward of the device, could not be moved inshore to the stillwater line by the device in its present form for at least some common wave and slope conditions.

i. Run 9. For Run 9, the device was returned to deeper water and set so that three of its flap valves would be operable. The profile remained as it was at the end of Run 8, which resembled the equilibrium profile shown in Figure 5. The offshore water depth remained at 30 feet, but the wave period was increased to 9 seconds, and the average offshore wave height

to three feet. Run 9 was a static run in order to observe the single-station behavior of the device under this new set of wave conditions. The run was about one hour and 17 minutes in duration. As may be noted in Figure 14, the device was located about one-third of the way down the final offshore slope. This slope, prior to Run 9, continued down to the tank bottom rather evenly with but a small level step about one-third of the way up from the bottom. The lower edge of the deepest flap extended to a depth of about 14 feet below the stillwater line. A trench of considerable width and depth was dug during Run 9, and caused the accretion of a rather sizable mound landward up the slope. Seaward of the trench, the device caused the accretion of two smaller layers of sediment, one immediately seaward of the trench rim, and the other immediately seaward of the previously mentioned level step in the slope. These two areas of accretion were separated by a small area of erosion when the level step in the slope had been.

Landward of the device location, about 132 cubic feet accreted, (all in the mound) and 82 cubic feet eroded (all in the trench) for a net gain of 50 cubic feet. Seaward of the device, an erosion of 149 cubic feet occurred, mostly from the trench but with some from the downslope step, while the two areas of accretion seaward amounted to about 154 cubic feet, a net accretion of 5 cubic feet. The extra accretional material was most probably contributed both from offshore and headward erosion not surveyed. The results of this run indicated that the device might be somewhat effective in waves of longer period.

j. Run 10. The purpose of Run 10 was primarily to attempt to move the mound of material accreted landward of the device during Run 9 farther inshore. As may be noted in Figure 15, this did not happen. Run 10 was of the mobile type, with the device being moved approximately every hour and 17 minutes for a total distance of 5 feet with the device at two locations and a total running time of 2 hours and 35 minutes. At its final location, the flap valve rack was tilted 30° with the lowest flap nearer the shore. This was done to attempt to force the sediment, placed in suspension by the under-device current generated by the passage of the wave trough, to remain closer to the seaward side and so make more suspended sediment available to be flushed through the open valves with the passage of the subsequent crest. As the device would be working in shallower water than it was in Run 9, it was set so that two valves would be operating. At this setting, the lowest edge of the deepest flap would extend about 9.5 feet beneath the stillwater line with the device in a vertical attitude.

For this run, the waves had the same 9-second period as in Run 9, but their offshore height was decreased a small amount to average 2.7 feet in 30 feet of water. The device caused a very small mound of accretion (see Figure 15) rather high up on the level portion of the profile above the slope. Seaward of this small mound, the device eroded a considerable amount of material down the slope to the wide, but rather shallow, trench dug during Run 10. This erosion created a gentler seaward slope, but removed all of the material accreted landward of the device during Run 9, plus more material up the slope. Seaward of the device location during Run 10, a large mound of accretion more than filled the large trench created during Run 9.

Landward of the device final location, about 11 cubic feet of material accreted, while 258 cubic feet eroded, producing a net loss of 247 cubic feet. Seaward of the final position, about 228 cubic feet of material accreted, while only 6 eroded, producing a net accretion of 222 cubic feet. It appeared rather clearly in this run that the sediment eroded from the landward side of the device was deposited on its seaward side. Tilting the flap rack shoreward also seems to have produced negative results.

k. Run 11. For Run 11, the device was relocated on the level shelf inshore of its position during Run 10 (see Figure 16). Since it was to operate in shallow water, the device was reset so that only one flap was operable. It was to be operated while in a vertical attitude so the lowest edge of the flap extended about 5 feet below the stillwater surface. It was hoped that a mound of accretion, similar to that created inshore of the device during Run 7, would be repeated, and perhaps be even larger, considering the 9-second wave period with an offshore average wave height of 3.4 feet that was to be used during Run 11. This run was of the static type, with the device remaining on station for about one hour and 17 minutes of wave action. As shown in Figure 16, no mound was accreted landward of the device, but a very wide and deep trench was dug beneath its position. Seaward of the rim of this trench was a rather thick layer of accreted material covering the slope. At the downslope terminus of the accreted material, a small pocket of erosion occurred. While no sediment was accreted inshore of the device, 126 cubic feet eroded, all from the landward portion of the trench. Seaward, however, 253 cubic feet eroded, mostly from the trench, but 375 cubic feet accreted, producing a net seaward gain of 122 cubic feet.

Run 11 tended to reinforce the idea that the flotation pad pumping effect, noted in Run 7, was significant in the accretion of the large mound inshore of the device, and that without that effect, with the device moving normally as in Run 11, no landward accretion would be realized.

l. Run 12. For this run, the device was moved only a short distance inshore from its position during Run 11, so that a significant amount of material would be accreted to landward. As may be noted in Figure 17, this did not happen. Run 12, again, was of the static type and lasted for one hour and 17 minutes, as did Run 11. The wave period for this run was 9 seconds as before, but the average offshore wave height was increased to 3.6 feet in 30 feet of water. As the device was to be located just over the inshore slope of the trench dug during the preceding run, it was set so that two flaps would be operative, the edge of the lowest one extending about 9.5 feet below the stillwater line with the device in a vertical attitude. This run caused a small mound of accretion, about 19 cubic feet in volume, to be created with its apex about 52 feet inshore of the device location. The device eroded a trench almost as deep as that dug during Run 11, but of considerable width on its inshore slope. The creation of this broad but rather gentle inshore slope, beginning at the seaward limit of the accreted mound and extending to the point of maximum trench depth, succeeded in eliminating most of the level area inshore of the device location noted in the two previous runs.

As may be seen in Figure 17, much of the 228 cubic feet eroded from inshore of the device during Run 12 was accreted seaward, partially filling the trench dug during Run 11, and spilling down the slope into deeper water. The erosion of several steps of the slope was noted, alternating with rather thin layers of accretion, with the result that 152 cubic feet eroded seaward of the device, while 486 cubic feet accreted, a net seaward accretion of 334 cubic feet, versus a net landward erosion of 209 cubic feet. Even with the rather long wave period, the device was unable to create a sizable mound of accretion landward of its position. It is also worth noting that the previously mentioned pumping effect of the flotation pads was not noted in Run 12.

m. Run 13. After Run 12, the wave period was changed to 7 seconds. The post-Run 12 profile indicated that an equilibrium profile was needed for the third wave condition of the test series. Accordingly, a 1:15 molded slope was made in the flume and waves having an average wave height of 4.4 feet in 38.7 feet of water, and a 7-second period were allowed to impinge on it for approximately 154 hours at the end of which time near equilibrium was reached. This equilibrium profile is shown in Figure 18. Since Run 13 required a new set of wave conditions, the test was to be a static one, with the device being set so that 3 flaps were operative, the lowest of these extending to a depth of about 14 feet below the stillwater line. Run 13 was of about 11 minutes duration, but of profound effect on the profile. The change in the equilibrium profile was so great that it was almost certainly caused by the presence of the device in operation, although the trench dug during Run 13 was neither especially wide, nor deep. As may be seen in Figure 18, a small mound of accreted material (about 17 cubic feet) was present inshore from the trench rim after Run 13. In this case, the inshore terminus of this mound has been considered the landward limit of the direct effect of the device operation. A rather long seaward accretion layer was noted extending from the offshore trench rim about 66 feet seaward to the shelf break. In the region near the stillwater line, a considerable amount of headward erosion occurred, causing a rather large amount of sediment to be deposited seaward in a layer of tapering thickness terminating on the shelf a short distance landward of the small accretion mound inshore of the device.

On the landward side of the device, 572 cubic feet accreted, 587 cubic feet eroded. On the seaward side, 61 cubic feet eroded, and 101 cubic feet accreted. Thus a net loss of material attributable to the operation amounting to 15 cubic feet accrued on the landward side of the device and a net gain of 40 cubic feet was registered on the seaward side.

n. Run 14. For Run 14, the offshore water depth was lowered to 34.5 feet, but the average wave height of 4.4 feet and period of 7 seconds remained, as in Run 13. For this mobile run, the initial position of the device was identical with that in Run 13. With the exception of the second position, the device was moved 3 feet every 11 minutes. The 22-minute stay at the second position produced no noticeable effect on the final profile, which was taken after about 2 hours and 20 minutes of running time, when

the device had operated over a distance of about 30 feet. As in Run 13, the device had a vertical attitude with 3 flaps operating, the lowest one extended about 14 feet below the stillwater line. The decrease in the water depth lowered the maximum elevation of wave attack on the shoreline and greatly decreased the amount of headward erosion that occurred during this run. However, some erosion did take place, providing sediment which created an offshore bar and a rather thick layer seaward down the shelf. The device dug a deep, wide trench and deposited mounds of material near both the inshore and offshore rims.

Landward of the device, 499 cubic feet accreted, and 397 cubic feet eroded; on the seaward side, 476 cubic feet eroded, and only 375 cubic feet accreted. A net accretion of about 100 cubic feet resulted on the landward side and a net erosion of the same amount resulted seaward. This run terminated the testing under this particular set of wave conditions.

o. Run 15. The purpose of Runs 15 and 16 was to observe the operation of the device in waves of low height and long period. Such wave conditions naturally tend to cause the accretion of material on beaches. Accordingly, the offshore water depth was set at 30 feet, the wave period at 15 seconds, and the average offshore wave height at 2.8 feet. A 1:15 molded slope was subjected to these waves for approximately 154 hours until a new equilibrium profile was obtained as shown in Figure 20. The device was then set in the vertical position so that 3 flaps operated, the lowest about 14 feet below the stillwater line. As a mobile run was required, the device was moved 3 feet approximately every hour during a total test time of about 5 hours and 49 minutes, a total distance of 15 feet. The rather long wave used in attaining an equilibrium profile, created a broad, essentially bimodal, offshore bar over which the device operated during Run 15. The device was positioned between the peaks and, as usual, dug a trench beneath it, the deepest portion thereof being near its final station. A group of small mounds accreted on top of the inshore lobe of the bar, landward of the trench rim. Similarly, a single mound accreted atop the more offshore peak on the bar seaward of the trench. Farther offshore, this accreted sediment tapered down the slope in a thin filet.

Landward of the device, 49 cubic feet accreted, and only 35 cubic feet eroded, leaving a net gain of 14 cubic feet. Seaward of the device, much more activity was noted with the accretion of 124 cubic feet and the erosion of 94 cubic feet. The amount of sediment accreted landward of the device was considered too small to attempt to move it toward the shore, so the device was moved inshore of the bar for the next run.

p. Run 16. The water depth remained at 30 feet for Run 16, the offshore wave height at 2.8 feet, and the period at 15 seconds. As in Run 15, the device remained set with 3 operating flaps extending to 14 feet below the stillwater line. This mobile run lasted 19 hours and 22 minutes, with the device being moved 3 feet about every hour, for a total distance of 57 feet. Several small low mounds accreted slightly above and below the stillwater shoreline (see Figure 21). The device eroded away the inner bar and some of the slope, which probably supplied not only the small amount of

sediment for the shoreline area accretion, but considerably more sediment for accretion seaward of the device, which began on the offshore side of the trench and continued seaward, filling the trench created during Run 15, then tapering down the slope. The peaks of the accretion mounds remaining after Run 15 were slightly eroded, also supplying some sediment.

Planimetering the compared profiles from this run and Run 15 shows that 58 cubic feet accreted on the landward side of the device, 187 cubic feet eroded, a net erosion of 129 cubic feet. Seaward of the device, 355 cubic feet accreted and 205 cubic feet eroded, a net accretion of 150 cubic feet. The rather small amount of accretion that occurred landward of the device during this run would appear to demonstrate an unsuccessful dredging device, especially in light of the beach-building wave characteristics employed during this run.

4. Conclusions

The results and analyses indicate that the device, in its present form, is unsuitable for moving sand shoreward from offshore sources. Table 8 shows that the results are not entirely consistent. For example, during Run 7, the novel behavior of the flotation pads acting in conjunction with the flap valves appeared to produce a pumping effect that may well have caused the resultant mound of accreted material. This mound was not moved shoreward during Run 8 in spite of the similarity of the impinging wave conditions. Run 14 is the only other run in which significant landward accretion occurred, but the effect of the beach-building wave used for the run is not known. The small positive net gain from Run 15, and the negative result from Run 16, cast doubt on the usefulness of the device, even under beach-building wave conditions. The offshore wave height was reduced 46 percent by the presence and operation of the device during Run 16. This decrease represents a usage and reflection of about 70 percent of the offshore impinging wave energy, yet the energy was obviously used to move sediment offshore rather than onshore.

Such variegated results are more than likely byproducts of the scale effects present in the test. For example, the device was tested over a coal profile over slopes averaging about 1 on 18, while in nature, shoreface slopes steeper than 1 on 60 are quite uncommon. Another area in need of more understanding is that of the water mass transport profile, that is, the onshore-offshore velocity distribution over the shoreface. A comprehensive understanding of this phenomenon and its relationship with the presence and operation of the device would probably cast considerable light on the results.

The operation of the device, however, serves to illustrate the possibility of a great potential for the utilization of wave power. It appears that if the sediment placed in suspension with the passage of the wave trough could be directed so as to remain within the region of the landward motion of the next wave crest, and if this landward current could be directed to place the sediment far enough inshore to be beyond the reach of the trough-generated seaward current, a similar device might prove successful.

TABLE I

Basic Run Characteristics

Run	Test Type	Slope Condition Before Run	Duration Model	Duration Prototype
1	Static	Equilibrium Profile	13 min.	0 hrs. 50 min.
2	Static	Run 1	13 min.	0 hrs. 50 min.
3	Static	Run 2	13 min.	0 hrs. 50 min.
4	Static	Run 3	13 min.	0 hrs. 50 min.
5	Mobile	Run 4	120 min.	7 hrs. 43 min.
6	Static	Run 5	20 min.	1 hr. 17 min.
7	Mobile	Run 6	390 min.	25 hrs. 10 min.
8	Mobile	Run 7	600 min.	38 hrs. 44 min.
9	Static	Run 8	20 min.	1 hr. 17 min.
10	Mobile	Run 9	40 min.	2 hrs. 35 min.
11	Static	Run 10	20 min.	1 hr. 17 min.
12	Static	Run 11	20 min	1 hr. 17 min.
13	Static	Equilibrium Profile	3 min.	0 hrs. 11 min.
14	Mobile	Run 13	36 min.	2 hrs. 19 min.
15	Mobile	Equilibrium Profile	90 min.	5 hrs. 49 min.
16	Mobile	Run 15	300 min.	19 hrs. 22 min.

TABLE 2

Wave Conditions and Water Depths

Run	Wave Period Model	Wave Period Prototype	Offshore Water Depth Model	Offshore Water Depth Prototype	Average Offshore Wave Height Model	Average Offshore Wave Height Prototype
1	1.291 sec.	5 sec.	2.00 ft.	30.0 ft.	0.12 ft.	1.8 ft.
2	1.291 sec.	5 sec.	2.00 ft.	30.0 ft.	0.10 ft.	1.5 ft.
3	1.291 sec.	5 sec.	2.00 ft.	30.0 ft.	0.10 ft.	1.5 ft.
4	1.291 sec.	5 sec.	2.00 ft.	30.0 ft.	0.11 ft.	1.6 ft.
5	1.291 sec.	5 sec.	2.00 ft.	30.0 ft.	0.10 ft.	1.5 ft.
6	1.291 sec.	5 sec.	2.00 ft.	30.0 ft.	0.09 ft.	1.4 ft.
7	1.291 sec.	5 sec	2.00 ft.	30.0 ft.	0.07 ft.	1.1 ft.
8	1.291 sec.	5 sec.	2.00 ft.	30.0 ft.	0.10 ft.	1.5 ft.
9	2.324 sec.	9 sec.	2.00 ft.	30.0 ft.	0.20 ft.	3.0 ft.
10	2.324 sec.	9 sec.	2.00 ft.	30.0 ft.	0.18 ft.	2.7 ft.
11	2.324 sec.	9 sec.	2.00 ft.	30.0 ft.	0.23 ft.	3.4 ft.
12	2.324 sec.	9 sec.	2.00 ft.	30.0 ft.	0.24 ft.	3.6 ft.
13	1.169 sec.	7 sec.	2.58 ft.	38.7 ft.	0.29 ft.	4.4 ft.
14	1.169 sec.	7 sec.	2.30 ft.	34.5 ft.	0.29 ft.	4.4 ft.
15	3.873 sec.	15 sec.	2.00 ft.	30.0 ft.	0.19 ft.	2.8 ft.
16	3.873 sec.	15 sec.	2.00 ft.	30.0 ft.	0.19 ft.	2.8 ft.

TABLE 3

Reduction in Wave Height Caused by Device

Run	Average Wave Height Offshore (in feet)*		Average Wave Height Inshore (in feet)**		Wave Height Reduction
	Model	Prototype	Model	Prototype	
1	0.12 ft.	1.8 ft.	0.09 ft.	1.4 ft.	22%
2	0.10 ft.	1.5 ft.	0.09 ft.	1.4 ft.	7%
3	0.10 ft.	1.5 ft.	0.05 ft.	0.8 ft.	47%
4	0.11 ft.	1.6 ft.	0.04 ft.	0.7 ft.	56%
5	0.10 ft.	1.5 ft.	0.07 ft.	1.1 ft.	27%
6	0.09 ft.	1.4 ft.	0.08 ft.	1.2 ft.	14%
7	0.07 ft.	1.1 ft.	0.04 ft.	0.6 ft.	46%

*For the Offshore Gage, distance offshore from the tank end wall was 43 feet in the model, 645 feet in the prototype.

** For the Inshore Gage, distance offshore from the tank end wall was 10.4 feet in the model, 156 feet in the prototype.

TABLE 4

Device Location

Run	Original Position*		Final Position**		Distance Moved	
	Model	Prototype	Model	Prototype	Model	Prototype
1	18.00 ft.	270 ft.	18.00 ft.	270 ft.	no movement	
2	17.70 ft.	266 ft.	17.70 ft.	266 ft.	no movement	
3	15.60 ft.	234 ft.	15.60 ft.	234 ft.	no movement	
4	14.45 ft.	217 ft	14.45 ft.	217 ft.	no movement	
5	14.20 ft.	213 ft.	13.20 ft.	198 ft.	1.00 ft.	15 ft.
6	10.60 ft.	159 ft.	10.60 ft.	159 ft.	no movement	
7	10.00 ft.	150 ft.	7.60 ft.	114 ft.	2.40 ft.	36 ft.
8	7.80 ft.	117 ft.	4.00 ft.	60 ft.	3.80 ft.	57 ft.
9	15.50 ft.	232 ft.	15.50 ft.	232 ft.	no movement	
10	15.00 ft.	225 ft.	14.70 ft.	220 ft.	0.30 ft.	5 ft.
11	9.00 ft.	135 ft.	9.00 ft.	135 ft.	no movement	
12	8.50 ft.	127 ft.	8.50 ft.	127 ft.	no movement	
13	19.50 ft.	292 ft.	19.50 ft.	292 ft.	no movement	
14	19.50 ft.	292 ft.	17.50 ft.	262 ft.	2.00 ft.	30 ft.
15	17.00 ft.	255 ft.	16.00 ft.	240 ft.	1.00 ft.	15 ft.
16	12.90 ft.	194 ft.	9.10 ft.	136 ft.	3.80 ft.	57 ft.

* Feet offshore from tank end wall

** Feet offshore from tank end wall

TABLE 5

Device Setting

Run	Depth of Deepest Part of Device (in feet) Model	Prototype	Number of Flap Valves Operating
1	1.33 ft.	19.9 ft.	4
2	1.33 ft.	19.9 ft.	4
3	1.03 ft.	15.4 ft.	4
4	0.92 ft.	13.8 ft.	3
5	0.92 ft.	13.8 ft.	3
6	0.34 ft.	5.1 ft.	1
7	0.34 ft.	5.1 ft	1
8	0.34 ft.	5.1 ft.	1
9	0.92 ft.	13.8 ft.	3
10	0.63 ft.	9.4 ft.	2
11	0.34 ft.	5.1 ft.	1
12	0.63 ft.	9.4 ft.	2
13	0.92 ft.	13.4 ft.	3
14	0.92 ft.	13.8 ft.	3
15	0.92 ft.	13.8 ft.	3
16	0.92 ft.	13.8 ft.	3

TABLE 6

Effect of Device Operation on Landward Side

Run	Accretion (in cubic feet) Model	Prototype	Erosion (in cubic feet) Model	Prototype
1	0.007	24	0.003	10
2	0.007	22	0.006	21
3	0	0	0.001	4
4	0.036	123	0.056	189
5	0.040	134	0.065	218
6	0.018	62	0.014	46
7	0.064	218	0.010	35
8	0.009	30	0.008	25
9	0.039	132	0.024	82
10	0.003	11	0.076	258
11	0	0	0.038	126
12	0.006	19	0.068	228
13	0.170	572	0.174	587
14	0.148	499	0.118	397
15	0.015	49	0.010	35
16	0.017	58	0.056	187

TABLE 7

Effect of Device Operation on Seaward Side

Run	Accretion (in cubic feet)		Erosion (in cubic feet)	
	Model	Prototype	Model	Prototype
1	0.014	49	0.010	35
2	0.008	25	0.006	19
3	0.014	48	0.008	27
4	0.008	27	0.018	62
5	0.074	248	0.026	89
6	0.008	25	0.017	58
7	0.011	38	0.094	319
8	0.143	483	0.140	472
9	0.046	154	0.044	149
10	0.068	228	0.002	6
11	0.111	375	0.075	253
12	0.144	486	0.045	152
13	0.030	101	0.018	61
14	0.111	375	0.141	476
15	0.037	124	0.028	94
16	0.105	355	0.061	205

TABLE 8

Net Effect of Device Operation

Run	Net Accretion (+) or Erosion (-) Landward of Device (in cubic feet)		Net Accretion (+) or Erosion (-) Seaward of Device (in cubic feet)	
	Model	Prototype	Model	Prototype
1	+0.004	+14	+0.004	+14
2	+0.003	+ 1	+0.002	+ 6
3	-0.001	- 4	+0.006	+22
4	-0.020	-66	-0.010	-35
5	-0.025	-84	+0.047	+159
6	+0.005	+16	-0.010	-33
7	+0.054	+182	-0.083	-281
8	+0.002	+ 5	+0.003	+11
9	+0.015	+50	+0.002	+ 5
10	-0.0732	-247	+0.066	+222
11	-0.038	-125	+0.036	+122
12	-0.062	-209	+0.099	+334
13	-0.004	-15	+0.012	+40
14	+0.030	+101	-0.030	-101
15	+0.004	+14	+0.009	+30
16	-0.038	-129	+0.044	+150

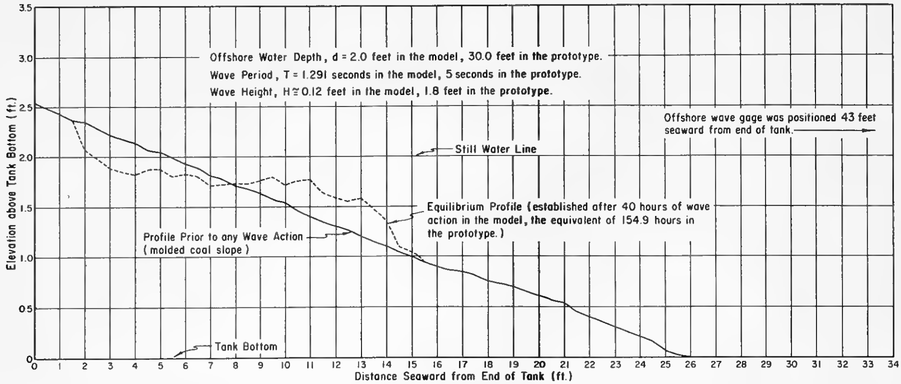

FIGURE 5. MOLDED SLOPE VERSUS EQUILIBRIUM PROFILE FOR FIRST WAVE CONDITION

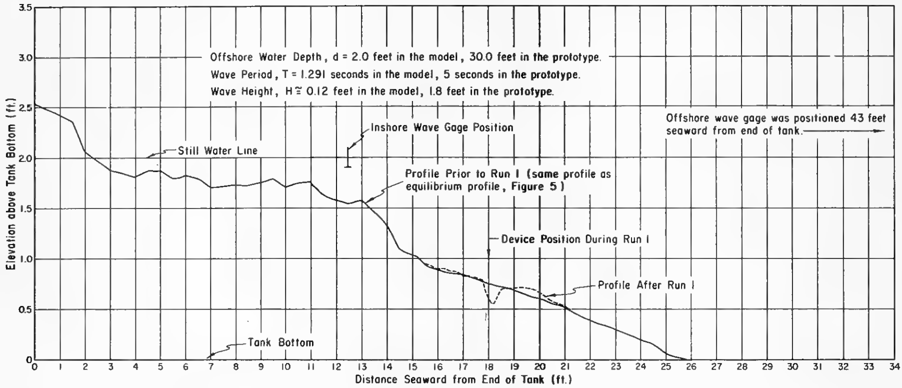

FIGURE 6. PROFILE MADE AFTER RUN 1 VERSUS EQUILIBRIUM PROFILE FOR FIRST WAVE CONDITION

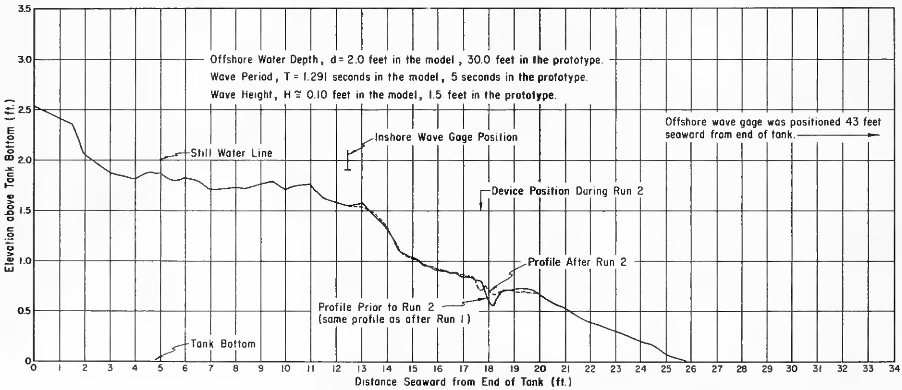

FIGURE 7. PROFILE MADE AFTER RUN 2 VERSUS PROFILE MADE AFTER RUN 1

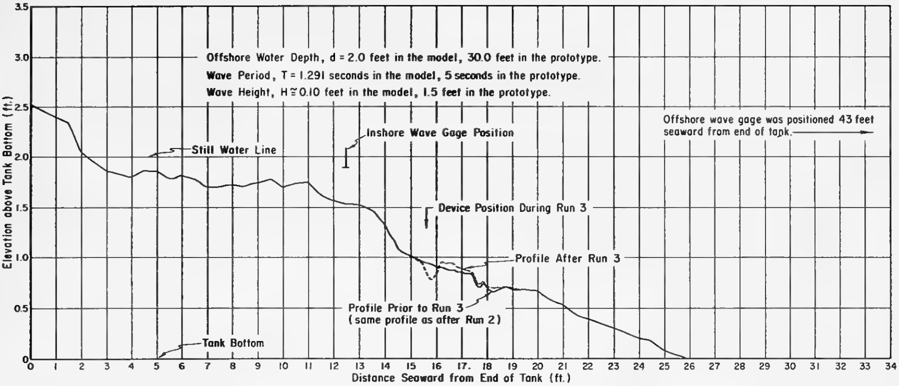

FIGURE 8. PROFILE MADE AFTER RUN 3 VERSUS PROFILE MADE AFTER RUN 2

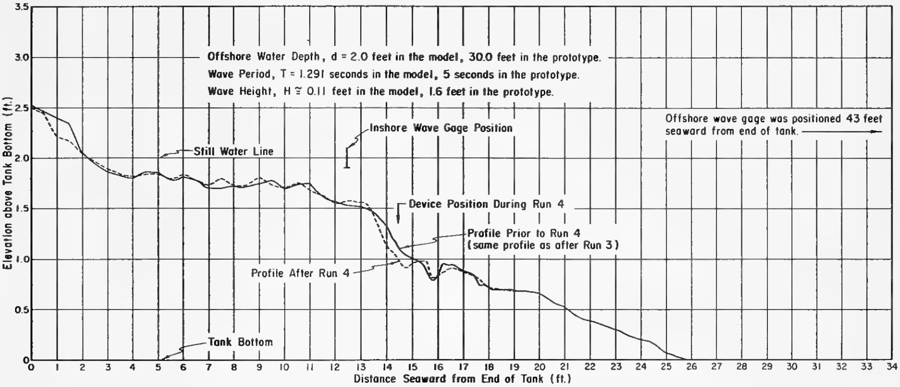

FIGURE 9. PROFILE MADE AFTER RUN 4 VERSUS PROFILE MADE AFTER RUN 3

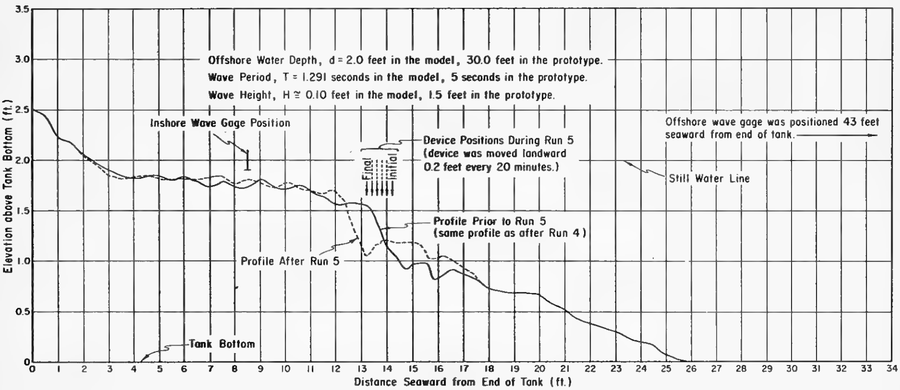

FIGURE 10. PROFILE MADE AFTER RUN 5 VERSUS PROFILE MADE AFTER RUN 4

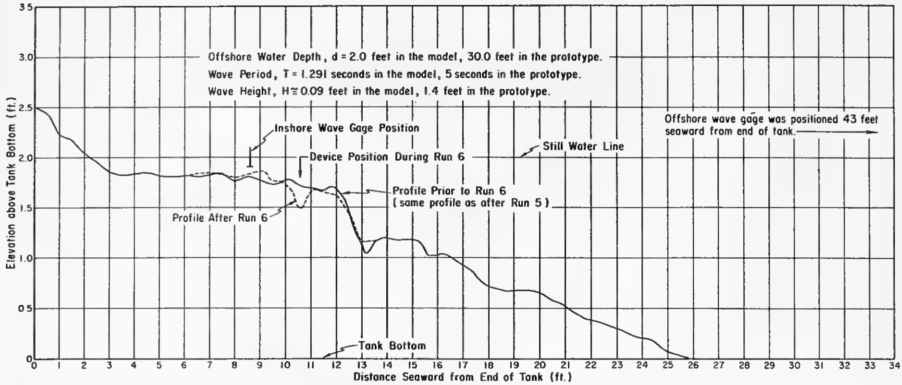

FIGURE 11. PROFILE MADE AFTER RUN 6 VERSUS PROFILE MADE AFTER RUN 5

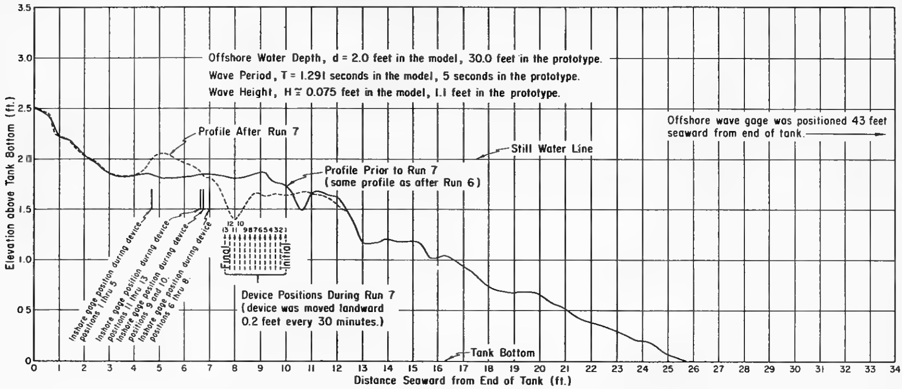

FIGURE 12. PROFILE MADE AFTER RUN 7 VERSUS PROFILE MADE AFTER RUN 6

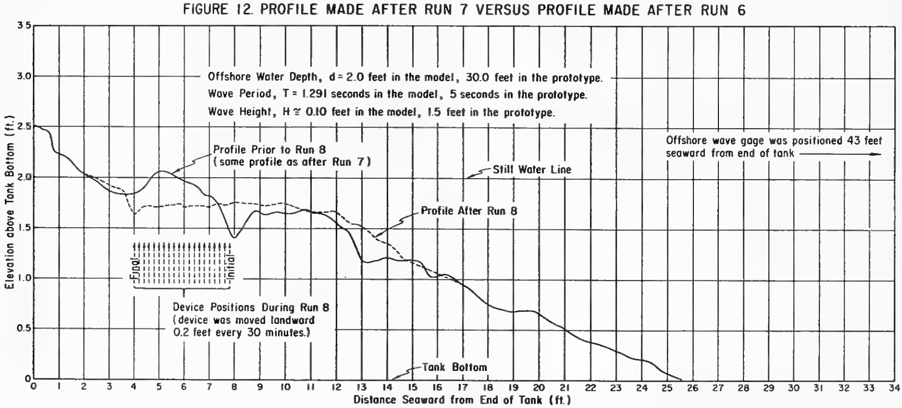

FIGURE 13. PROFILE MADE AFTER RUN 8 VERSUS PROFILE MADE AFTER RUN 7

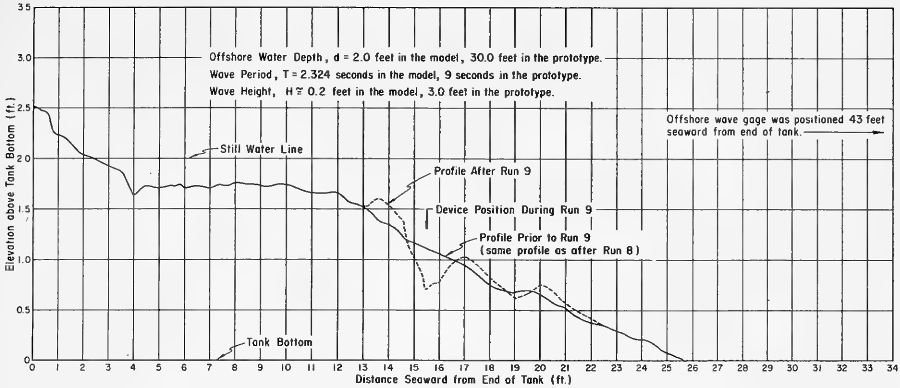

FIGURE 14. PROFILE MADE AFTER RUN 9 VERSUS PROFILE MADE AFTER RUN 8

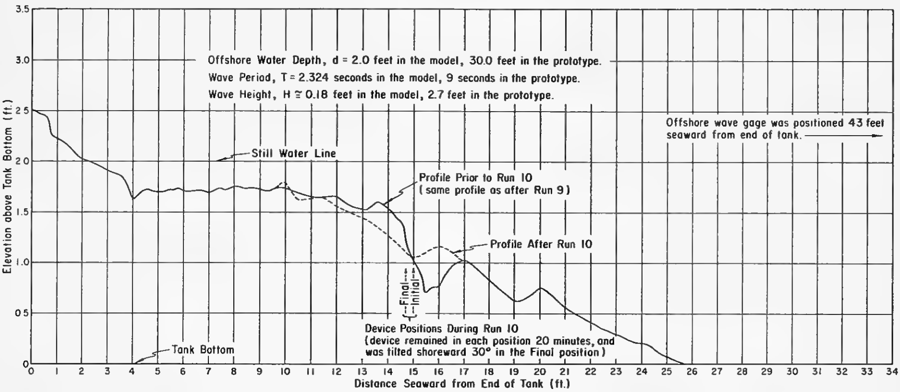

FIGURE 15. PROFILE MADE AFTER RUN 10 VERSUS PROFILE MADE AFTER RUN 9

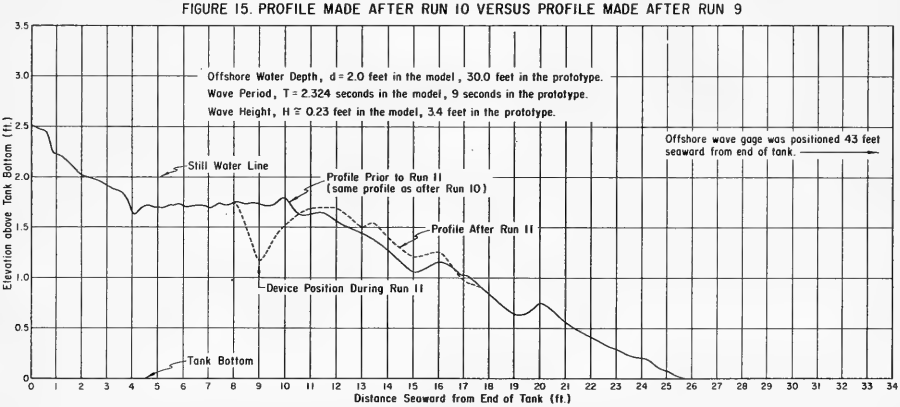

FIGURE 16. PROFILE MADE AFTER RUN 11 VERSUS PROFILE MADE AFTER RUN 10

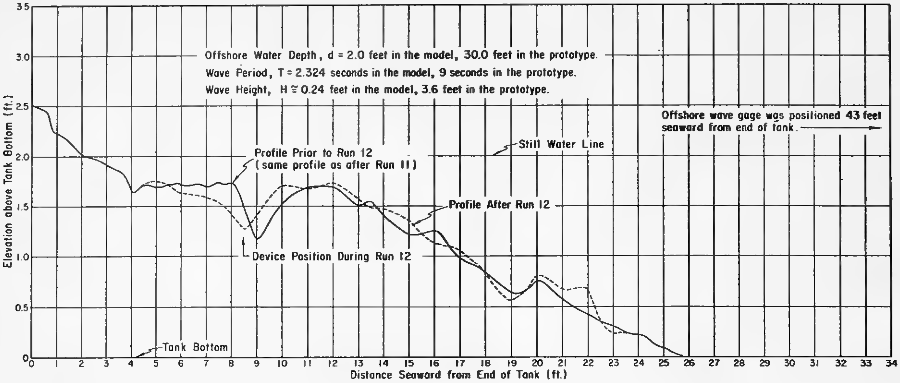

FIGURE 17. PROFILE MADE AFTER RUN 12 VERSUS PROFILE MADE AFTER RUN 11

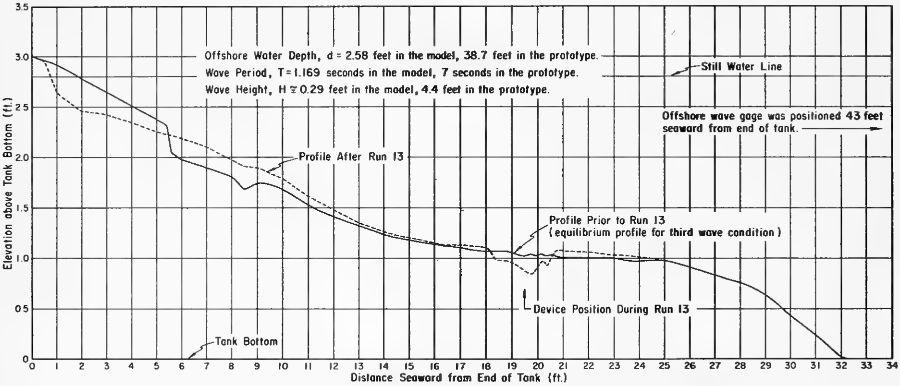

FIGURE 18. PROFILE MADE AFTER RUN 13 VERSUS EQUILIBRIUM PROFILE FOR THIRD WAVE CONDITION

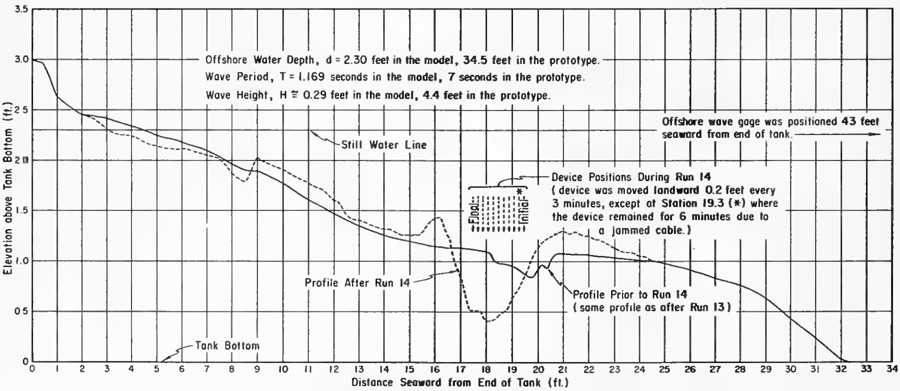

FIGURE 19. PROFILE MADE AFTER RUN 14 VERSUS PROFILE MADE AFTER RUN 13

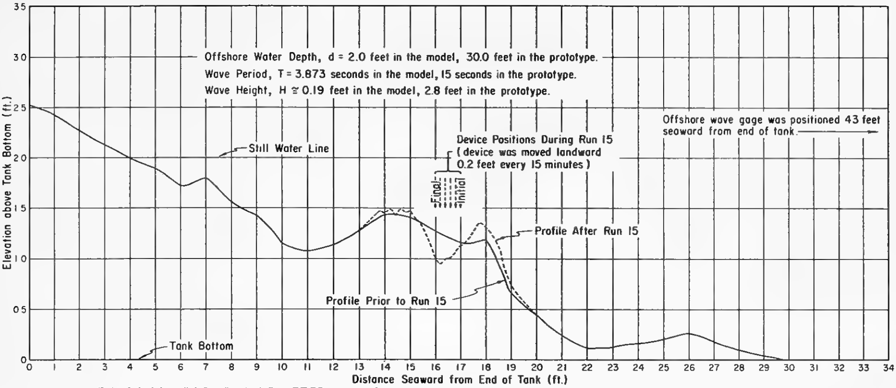

FIGURE 20. PROFILE MADE AFTER RUN 15 VERSUS EQUILIBRIUM PROFILE FOR FOURTH WAVE CONDITION

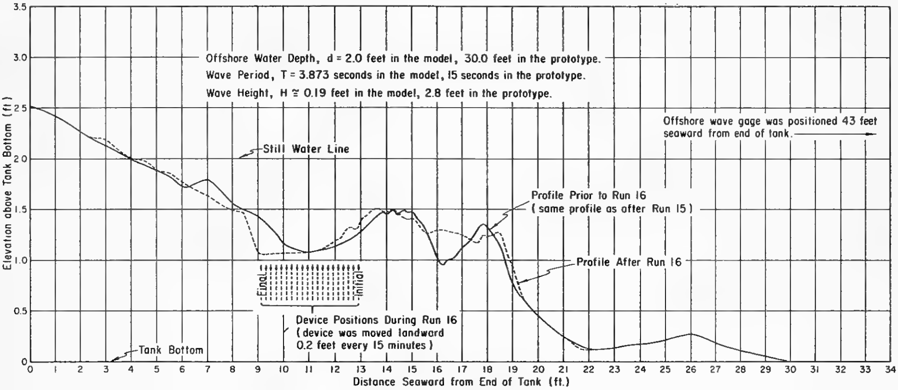

FIGURE 21. PROFILE MADE AFTER RUN 16 VERSUS PROFILE MADE AFTER RUN 15

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